Physical form of the diet in relation to rumen fermentation

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This paper deals principally with alteration to the physical form of forage diets and the effect on rumen fermentation. When a forage crop is cut and conserved there are possibilities of (a) changing the physical and chemical characteristics of the forage before it is given and (b) of combining the forage with other food components. To produce a ruminant ration of high nutrient potential both these measures should be based on nutritional principles. Information on mixed diets is limited (Topps, Kay & Goodall, 1968; Topps, Kay, Goodall, Whitelaw & Reid, 1968; MacRae & Armstrong, 1969; Nicholson & Sutton, 1969). Lack of space precludes in this paper adequate examination of the effect of physical form of cereals (Armstrong & Beever, 1969) and of cereal straws (Lamming, Swan & Clarke, 1966; Pickard, Swan & Lamming, 1969; Swan & Lamming, 1970) and, also, liquid diets (Ørskov, Fraser & Corse, 1970) on rumen fermentation, and the paper has therefore been restricted to forage diets.

The choice of title for this symposium is appropriate, and timely. However, posing the problems of manipulation and control of rumen fermentation does highlight the question 'Manipulation to what end?'. Manipulation of rumen fermentation relates not only to the rumen but also to the host animal, the producing ruminant; the objective in controlling and manipulating rumen fermentation is to improve the efficiency with which the host animal utilizes its food for productive purposes.

The physical form, and in particular the particle size, of dried forages can be altered markedly from the original long or chopped form. In addition to grinding and pelleting, dried chopped forage may be compressed into wafers or cobs, forms which are intermediate between chopped and pelleted. Methods are available to define the effects of processing on particle size (American Society of Agricultural Engineers, 1967) but are too seldom used. Earlier work has been reviewed by Minson (1963), Moore (1964) and Meyer, Kromann & Garrett (1965). Quantification of fermentation within the rumen, and throughout the alimentary tract, is possible with the use of ruminant animals fitted with cannulas at the abomasum, duodenum and other parts of the tract (Hogan & Phillipson, 1960; Ash, 1962; Brown, Armstrong & MacRae, 1968). Although there are limitations, principally of technique, to a more exact understanding, and therefore control, these preparations do permit the study of rumen fermentation in vivo.

Digestion in the rumen

Altering the physical form of a forage diet by grinding and pelleting can increase the rate of digestion of most chemical constituents of the diet compared with the long or chopped form (Meyer *et al.* 1965); grinding and pelleting also increases the rate of passage of undigested and partially digested food particles and the associated micro-organisms. The net effect on digestion in the rumen of these simultaneous events has been measured with several processed forage diets, using sheep fitted with re-entrant cannulas in the proximal duodenum and the terminal ileum (Beever, Thomson & Harrison, 1971; Beever, Coelho da Silva, Prescott & Armstrong, 1972; Coelho da Silva, Seeley, Beever, Prescott & Armstrong, 1972; Coelho da Silva, Seeley, Thomson, Beever & Armstrong, 1972; Thomson & Beever, 1972; Thomson, Beever, Coelho da Silva & Armstrong, 1972). The results presented in Table 1 indicate that giving ground and pelleted forage diets twice daily generally reduced both total apparent energy digestibility and the amount of energy digested in the forestomachs (hereafter referred to as the rumen). An exception to this was found when the forage diet (lucerne) was dried at a low temperature, milled through a 3 mm screen and given at 3 h intervals (Hogan & Weston, 1967).

In six comparisons between ground, pelleted forage and either chopped or wafered diets, covering a digestibility range from 80 to 56% and including both grasses and legumes, ruminal digestion of energy was in each instance reduced by grinding and pelleting; 54% of the apparently digested energy in the chopped and wafered diets was digested in the rumen, compared with only 44% for the pelleted diets. With fresh herbage, hay or low-temperature dried forage in the chopped form, ruminal digestion normally accounts for some 60–70% of the energy digested in the alimentary tract (Hogan & Phillipson, 1960; Bruce, Goodall, Kay, Phillipson & Vowles, 1966; Topps, Kay & Goodall, 1968; Beever, Thomson, Pfeffer & Armstrong, 1971).

Based on measurements of the proportions of different volatile fatty acids (VFA) in rumen liquor samples withdrawn during restricted periods immediately post-feeding, it has been suggested that the production of propionic acid is higher and of acetic acid lower from pelleted forages than from the same forage given in the long form (Meyer *et al.* 1965). However, this has not been confirmed in experiments in which VFA production in the rumen has been measured by an isotope dilution technique on samples taken throughout the 24 h (Beever, Thomson & Harrison, 1971; Thomson & Beever, 1972). These experiments have shown that the decreased ruminal digestion of energy with pelleted forages is associated with a reduced total productions of VFA (Table 1); further, the net daily production of acetic, propionic and butyric acids were all reduced and limited observations suggested that the relative proportions of these three acids did not differ, over 24 h, between pelleted and chopped diets, although with each there were differences in composition within the 24 h (Beever, Thomson & Harrison, 1971; Thomson & Beever, 1972;Thomson *et al.* 1972). These results emphasize the importance of examining rumen fermentation over an adequate period of time, because the

Table 1. *Digestion in the rumen of forage diets of different physical form*

Forage crop	Physical form	Modulus of fineness	Apparent energy digestibility (%)	Energy digested in the rumen (expressed as kcal/100 kcal (kJ/100 kJ) DE/24 h)	Volatile fatty acids: Total (mol/24 h)	Volatile fatty acids: Molar proportion (%): Acetic	Pro-pionic	Butyric	Flow of nitrogen at duodenum (g/100 g OM digested)	Reference
Rye-grass	Chopped	3·3	80·6	58 (243)	—	—	—	—	7·8	Beever, Coelho da Silva, Prescott & Armstrong (1972) and Coelho da Silva, Seeley, Beever *et al.* (1972)
	Pelleted	1·3	74·4	52 (218)	—	—	—	—	8·7	
Rye-grass	Chopped	3·3	80·4	64 (268)	—	—	—	—	6·7	
	Pelleted	1·3	78·2	51 (213)	—	—	—	—	8·8	
Rye-grass	Chopped	3·2	70·8	54 (226)	—	—	—	—	8·6	
	Pelleted	1·1	71·2	51 (213)	—	—	—	—	8·7	
Cock's-foot	Wafered	3·1	67·9	50 (209)	4·06	71	20	9	7·2	Thomson & Beever (1972)
	Pelleted	0·8	59·4	37 (155)	3·64	69	20	11	11·5	
Red clover	Wafered	3·3	64·6	60 (251)	4·54	74	20	6	7·9	Beever, Thomson & Harrison (1971)
	Pelleted	1·8	66·0	48 (201)	3·65	75	18	7	10·2	
Lucerne	Chopped	3·5	56·5	39 (163)	—	62	25	13	12·7	Thomson *et al.* (1972)
	Pelleted	1·5	57·8	23 (96)	—	64	24	12	19·2	

DE, digestible energy; OM, organic matter.

pattern of eating and ruminating is influenced by the physical form of the diet. Ground, pelleted diets are more rapidly ingested than forage in the chopped form (Weston & Hogan, 1967). This rapid ingestion is associated with reduced rumination and salivation and with an increased rate of fermentation during the period immediately after feeding (Sutherland, 1963), and these lead to a marked reduction in rumen pH (Balch & Rowlands, 1957) and to a temporary enhanced production of propionic acid (Sutherland, 1963).

Rate of digestion of organic matter in the rumen is higher when pelleted forage diets are given. The digestion of soluble and readily-digestible constituents in pelleted diets may be completed in the rumen (Topps, Kay & Goodall, 1968); however, whereas the rate of digestion of structural carbohydrates is higher with the pelleted diet (Meyer *et al.* 1965), the more rapid rate of passage from the rumen may result in less cellulose being digested in the rumen. Thus with twice-daily feeding, the amount of cellulose digested daily in the rumen was reduced from 50 g/100 g ingested to 37 by grinding a lucerne diet (Thomson *et al.* 1972) and from 80 to 55 g/100 g by grinding a grass diet (Beever, Coelho da Silva *et al.* 1972). However, Hogan & Weston (1967) found no differences in the ruminal digestion of structural carbohydrates when chopped and pelleted lucerne were given at frequent intervals.

Total cellulose digestibility is commonly reduced by grinding and pelleting, particularly with grasses given at high planes of nutrition. However, the reduced extent of cellulose digestion within the rumen is at least partly compensated by an increased digestion within the caecum and colon (Thomson *et al.* 1972), although the nutritional significance of this effect is not yet clear.

Less is known, quantitatively, about protein digestion within the rumen; both proteolysis of food protein and synthesis of microbial protein occur at the same time.

Microbial synthesis in the rumen

Less organic matter (OM) and energy are digested in the rumen and the flow of these constituents at the duodenum is higher for ruminants given pelleted diets than for those given similar diets, but containing forage in the long form. Estimates of the microbial yield from rumen fermentation of diets containing forage in the long form have been variable (Hungate, 1966; Walker & Nader, 1968; Hobson & Summers, 1967; Hume, 1970). Hogan & Weston (1970) have used a value of 3·7 g nitrogen per 100 g OM digested in the rumen for the yield of bacterial nitrogen. There is less information on the contribution the microbial population makes to the digesta entering the duodenum of ruminants fed on pelleted diets, or whether the physical form of the diet influences microbial synthesis in the rumen.

If microbial synthesis is related in a consistent manner to the amount of energy or OM digested in the rumen, then the reduced digestion of energy in the rumen of sheep fed on pelleted diets should lead to less microbial protein leaving the rumen and entering the proximal duodenum; this was indicated in the results of simulated rumen studies with long and ground lucerne (Baldwin, Lucas & Cabrera, 1970). However, in vivo measurements of total N flow at the duodenum have been as high

https://doi.org/10.1079/PNS19720026 Published online by Cambridge University Press

or higher when pelleted diets, compared with chopped or wafered diets, have been given. As less OM is digested in the rumen on the pelleted diets, this indicates a greater flow of N per 100 g OM digested on the pelleted diets (see Table 1). If we assume that the endogenous flow of N at the duodenum is similar for diets of different physical form, then the greater flow of N on the pelleted diets could be either because more microbial protein is produced per 100 g OM digested, or because more undigested food N is reaching the duodenum. Both factors could be contributing to the higher flow of N on pelleted diets. However, in the absence of published results specifically related to pelleted diets, the value of 3·7 g bacterial N per 100 g OM digested has been used in conjunction with the estimate that bacterial protein comprises 60% of the total microbial protein (Gray, Pilgrim & Weller, 1958; Coelho da Silva, Seeley, Thomson *et al.* 1972) to calculate total microbial protein at the duodenum.

Estimates derived in this manner for the diets given in Table 1 have shown a lower production of microbial protein in the rumen for sheep fed on pelleted diets, so that the increased flow of N at the duodenum on pelleted diets was attributed to the passage of N of food origin. Non-microbial protein as a percentage of total N at the duodenum was calculated to be 46 and 42% for the pelleted cock's-foot and red clover diets and 15 and 22% respectively for the wafered forms. Similar results have been obtained with high digestibility rye-grasses (Coelho da Silva, Seeley, Beever *et al.* 1972) using the diets referred to in Table 1. For a lucerne diet of low-energy digestibility, 68% of the total N at the duodenum was calculated to be of non-microbial origin compared with 54% on the chopped form (Coelho da Silva, Seeley, Thomson *et al.* 1972).

Current techniques for estimating microbial synthesis in vivo (Walker & Nader, 1968; Hogan & Weston, 1970; Smith & McAllan, 1970), particularly when undegraded food protein is reaching the duodenum, are not entirely satisfactory and new methods for measuring microbial synthesis in the rumen are needed. A method (Harrison, Beever & Thomson, 1972) based on the use of ^{35}S (Henderickx, 1961; Roberts & Miller, 1969) has been tested (Beever, Harrison & Thomson, 1972) and shows promise.

Limited evidence, derived from the diets shown in Table 1, and based on the concentration and flow of methionine at the duodenum relative to the concentration and the amount of methionine consumed in the chopped and pelleted diets, suggests more efficient microbial growth in the rumen of sheep given pelleted diets. This, however, requires further study.

The effect of physical form of the diet on rate of passage of digesta from the rumen

Altering the physical form of a forage diet by grinding and pelleting leads to a faster rate of passage of undigested food particles (as measured by the stained-particle technique) from the rumen, and throughout the length of the alimentary tract (Blaxter, Graham & Wainman, 1956). The increased rate of passage from the rumen is probably the major factor contributing to the reduced digestion of energy in the rumen with animals fed on pelleted diets. The degree of fineness of grinding and the plane of nutrition both influence the rate of passage and the extent to which apparent digestibility is depressed (Blaxter *et al.* 1956). However, the stained-particle technique measures only undigested food particles. Though the rate of fluid movement from the rumen can also be readily measured, the movement of fine particles, which include micro-organisms and material of food origin, is less readily established (Pearce, 1967; Sutton, 1971).

The fluid intake of sheep fed on pelleted forage diets may be higher than with chopped diets (Potter, Walker & Forrest, 1972); although the rumen fluid volume and the total flow of fluid from the rumen may be lower, the rate of flow from the abomasum relative to the flow from the rumen is increased by grinding and pelleting (Weston & Hogan, 1967). With both cows (Campling & Freer, 1966) and sheep (Beever and Thomson, unpublished) the dry-matter content of the digesta leaving the rumen and entering the duodenum is higher for animals given pelleted compared with chopped diets.

Support for the suggestion of more efficient microbial growth in the rumen of sheep fed on pelleted diets may be drawn from continuous culture studies (Herbert, Elsworth & Telling, 1956; Hobson & Summers, 1967). The combination of high rates of fermentation and microbial growth in the periods immediately post-feeding, and a rapid rate of passage from the rumen, may influence the efficiency of microbial growth.

Rumen fermentation and the utilization by ruminants of diets of different physical form

The voluntary consumption of pelleted diets is normally higher than that of chopped diets (Minson, 1963; Moore, 1964). On the other hand, grinding and pelleting normally reduces the total apparent digestibility and the metabolizable energy (ME) content of the forage, although the ME is utilized with greater efficiency for growth and lipogenesis than that of diets in the chopped form (Blaxter & Graham, 1956; Paladines, Reid, Niekerk & Bensadoun, 1964; Thomson & Cammell, 1971; Thomson & Beever, 1972). As a result, the net energy content of the pelleted forage may be as high as that of the chopped forage, when pelleting causes a marked reduction in digestibility as with grass (Blaxter & Graham, 1956), or it may be higher when, as with legumes, grinding and pelleting causes only a small reduction in digestibility (Thomson & Cammell, 1971).

Several factors may contribute to the more efficient utilization of the ME from pelleted than from chopped forages. There are lower energy costs of eating and ruminating (Graham, 1964; Weston & Hogan, 1967), and also lower losses as methane (Blaxter & Graham, 1956) when pelleted diets are given. However, the major effect is likely to be the different pattern and extent of digestion and synthesis in the rumen, and subsequent digestion in the small intestine by host enzymes. Black (1971), from theoretical considerations, has estimated the efficiency of utilization of digested energy and protein resulting from either microbial fermentation of food (the 'ruminant' lamb), or digestion by host enzymes (the 'non-ruminant' lamb). These estimates were adjusted for patterns of fermentation and digestion occurring with forage and mixed forage–concentrate diets. The utilization of digested energy by the non-ruminant lamb was calculated to be 30–45% more efficient for maintenance and up to 60% more efficient for production than by the ruminant lamb.

The results with ground and pelleted forage diets, in which more efficient utilization of the digested nutrients was associated with greater postruminal digestion, when compared with the same diets given in the chopped form (Thomson & Cammell, 1971; Thomson & Beever, 1972; Thomson *et al.* 1972) have, additionally, several implications. It may be suggested that it is possible to develop ruminant diets which are processed – by altering the physical form, by heating or by chemical treatment – and are effectively digested by host enzymes and efficiently utilized, and that the rumen microflora are simultaneously 'fed' in a programmed or manipulative manner (with the addition of readily available energy and N) to maximize their yield within the rumen and also to digest the fibre contained in forage diets. With the techniques and methods now available it should be possible to manipulate rumen fermentation to achieve more efficient food utilization.

I would like to express my thanks to my colleagues Dr D. E. Beever, D. G. Harrison, Dr D. F. Osbourn and W. F. Raymond for their help and criticism in the preparation of this paper, and also to Professor D. G. Armstrong and his colleagues at Newcastle University who kindly provided information which was, at the time of writing, in the press.

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Printed in Great Britain